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by

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Abstract

This paper develops an ecological perspective on the relationship between industrial economies and the environment. The purpose is to derive some basic principles for stable environment-economy integration that will lend substance to the concept of "sustainable development."

Industrial nations continue to act as if the economy operates in isolation from "the environment." The latter serves as an infinite storehouse of resources and sink for wastes, but is otherwise perceived as static, inert, and passive. By contrast, we see the economy as a dynamic productive system whose continued growth can produce a bountiful material standard of living for all. Resource depletion and pollution are temporary manageable problems that can be solved through increased efficiency, improved technology, and better regulation. Linear mechanical thinking tells us that if we do push the environment too far, simply backing off will set things right again. By this reasoning, sustainable development becomes little more than a rationale for sustained economic growth. People remain free to pursue their individual material self-interest without limit in an economy devoid of morality or ethical choice.

From an ecological viewpoint, these perceptions are dangerously misleading. First, the notion of environment as distinct entity is a sociocultural myth. Far from being separate, the environment and the economy have always been fully and inextricably integrated. The human economy is a wholly dependent sub-system of the ecosphere. Second, rather than being inert and static, the ecosphere is a living dynamic system with the unique capacity to self-produce. By contrast, from a thermodynamic (rather than mechanical) perspective the material economy doesn't produce, it only consumes. Industrial economies merely convert ecological capital into economic capital and do so inefficiently. It follows that if the rate of conversion persistently exceeds the rate of formation of ecological capital, economic activity will inevitably lead to the destruction of the ecosphere. In this light, pollution and resource depletion are not the problem but the symptoms of ecological destabilization caused by a growing economy within a limited "environment."

By this analysis, sustainable development requires that we revise the material economic growth model, accept ecological limits on consumption, and learn to live on the interest of our remaining ecological capital (i.e., within the "carrying capacity" of the ecosphere). It also reintroduces ethical and moral considerations into the debate on global economic development in a world where 25% of the population presently consumes 75% of available resources. A set of principles for sustainable development consistent with this interpretation is presented.

The Ecological Meaning of Environment-Economy Integration[1]

Since being popularized by the Report of the World Commission on Environment and Development (The Brundtland Commission, WCED 1987), the venerable concept of "sustainable development" has inspired the enthusiasm of people on all sides of the economy-environment debate. In light of worsening global environmental trends, any concept that implies we can eat our developmental cake and have the environment too, is bound to have a certain popular appeal.

This does not mean there is agreement as to the nature of future development. To some ears, sustainable development is a long-awaited call for political recognition of global environmental decay, economic injustice, and limits to material growth. It therefore represents an opportunity for humanity to correct an historical error and develop a gentler, more balanced, and stable relationship with the natural world (see Robertson 1978, for an example). This view of sustainable development also raises moral considerations such as the need in a limited world for more equitable sharing of the world's resources (Kneen 1989).

But other people read a different message in Our Common Future. Indeed, the World Commission itself equated sustainable development with "more rapid economic growth in both industrial and developing countries" on grounds that "economic growth and diversification ...will help developing countries mitigate the strains on the rural environment, raise productivity and consumption standards, and allow nations to move beyond dependence on one or two primary products for their export earnings" (WCED 1987, p.89). Accordingly, the Commission indicates "a five- to ten-fold increase in world industrial output can be anticipated by the time world population stabilizes some time in the next century" (WCED 1987, p.213).

To those who regard present levels of industrial activity as the root cause of global environmental decline, the Commission's appeal for a "revitalization" of economic growth on this scale seems paradoxical at best - ballooning economic activity is simply not in the ecological cards. Nevertheless, the power of the growth paradigm is not to be underestimated. As sustainable development is gradually embraced by the political mainstream, its meaning drifts ever further from the ideal of sustainable environment toward the seductive temptation of sustainable material growth.

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[1] Prepared for the Ninth Commonwealth Conference on Human Ecology: "HUMAN ECOLOGY, SUSTAINABLE DEVELOPMENT, AND EDUCATION" (University of Edinburgh, 19-23 July 1989). (Based on Rees 1989a.)

This paper is an exploration of the ecological and thermodynamic implications of the environment-economy integration required for sustainable development. My premise is that our present environmental conundrum arises in part from a distorted perception of reality. Society operates from an outdated mechanistic perception of the economy and has only a rudimentary understanding of the dynamics of the environment.

If this premise is correct, our present understanding of the so-called environmental crisis is dangerously superficial and the possibility of sustainable development based on the growth-oriented assumptions of neo-classical economics is illusory. *No amount of ethical axiology, or legal, policy, and technological engineering is going to solve problems that are misunderstood* (Drengson 1989). It follows that significant changes in sociocultural beliefs, attitudes, and behaviour will be required before sustainable development acquires substantive meaning. (See Appendix 1 for a definition of sustainable development.)

1. THE CULTURAL ROOTS OF REALITY

How society relates to the rest of reality is profoundly affected by an elaborate set of unconscious "facts," unquestioned assumptions, and entrenched beliefs. These are derived ultimately from the shared experience of a people in the course of their social evolution and are transmitted culturally to each new individual as s/he matures in that particular milieu. Such a common philosophy or **world-view** shapes every culture's social relationships, its political institutions, and the nature of its economic enterprise.

1.1 World-View as Social Myth

It is important to realize that there can be as many world-views as their are cultures and that each world-view only more or less coincides with reality. Thus, our most sacred beliefs, however well sustained by the evidence to date, may simply be wrong. The important point is that while we think we act from factual **knowledge**, much individual action and government policy is based on unsubstantiated **belief**. Indeed, much of our world-view may be little more than social myth, a collection of "shared illusions" (see Beer 1981).

In some cases, it is of no great consequence when even our most profound beliefs (e.g., "the world is flat") depart from external reality. However, certain activities, long consistent with the prevailing world-view, may eventually produce a crisis if the cumulative effect ultimately comes in conflict with a previously unknown reality. In these circumstances, society must be prepared to modify its world-view to conform with its modified perception of truth. This paper argues that industrial civilization has reached such a critical juncture in its relationship with "the environment" and that a new set of assumptions is needed to inform our quest for meaning in the concept of sustainable development.

1.2 Nature Estranged: The Clockwork Universe

The scientific or Cartesian world-view that presently dominates western society is characterized by a mechanical view of the universe as "a vast machine, wound up by God to tick forever, and consisting of two basic entities: matter and motion" (Berman 1984, p.21). While it has much deeper roots, this vision flowered only in

the 17th Century and is most closely associated with Rene Decartes, Francis Bacon and Isaac Newton.

Descartes set the stage with his division of reality into the independent realms of mind and matter and his quest for a universal mathematics to measure and order the external world.[2] The ultimate rationalist, Decartes saw even man's activity as a thinking being as purely mechanical. The mind has a certain method and **confronts the world as a separate object**. "It applies this method to the object, again and again and again, and eventually it will know all there is to know" (Berman, p.20). Through the separation of the observer from the observed, Descartes helped formalize the notion of objective knowledge and his reductionist approach provided the methodological framework for all subsequent scientific enquiry.

Bacon represents the empiricist pole. He reasoned that to know nature one had to "vex" her, "torture nature's secrets from her" thus forcing her to yield unambiguous answers (Capra 1983, p.56). In addition to this essence of experimental method, Bacon gave the new science its *raison d'etre*. He argued that knowledge should be put to work allowing mankind to take command over the natural world, its objects, and its mechanical powers. "From this perspective, knowledge is regarded not as an end but as a means, expressed and applied in technology, by which humans assume power over the material world" (Jones 1987, p.236).

But it was Newton who ultimately succeeded in validating the Cartesian view of the universe. His Principia (1686) revealed the seemingly universal laws of mass and motion which describe the universe as a mechanical machine of unlimited dimensions behaving according to strict mathematical rules.

By the end of the 17th Century the founders of the scientific world-view had abolished the ancient organic perception of the earth as a living entity, the nurturing mother. "By separating and then eliminating all the qualities of life from the quantities of which they are a part, the architects of the machine paradigm [left us] with a cold, inert universe made up entirely of dead matter" (Rifkin 1981, p.22).

1.3 Material Man

It remained only for two additional thinkers to apply the mechanical world-view directly to human institutions and affairs. John Locke was driven to determine the "natural" basis of society. With God alienated from nature, Locke reasoned that religion could also no longer provide the rational basis for government. People had to create their own meaning, and the purpose of society was reduced to protecting and encouraging the increase of the property of its members (Rifkin 1981, p.24). Indeed, Locke argued that the ownership of property conveyed not only rights, but an obligation to generate wealth: "He who appropriates land to himself by his labour, does not lessen but increases the common stock of mankind" (Locke 1967, p.312). Similarly, "land that is left wholly to nature ... is called, as indeed it is, waste" (Locke 1967, p.315).

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[2] This follows from Galileo's division of reality into the subjective (unmeasurable and therefore unreal) and the objective (accessible to science through measurement and mathematical analysis).

Similar logic underpined the "invisible hand" of Adam Smith. Smith argued that just as the planets conform to natural laws, so must economic behaviour obey subtle natural forces. Smith, like Locke, believed that the basis of all human activity was material self-interest, "but the study of [a person's] own advantage naturally, or rather necessarily, leads him to prefer that employment which is most advantageous to society" (Smith 1961, 1:475).

By this reasoning, "any attempt by society to guide 'natural' economic forces [would be] inefficient" (Rifkin 1981, p.26). Interference with the workings of the "invisible hand" for whatever noble purpose would only stifle economic growth. Significantly, this effectively excluded morality from the realm of political economy. "There are no ethical choices to be made, only utilitarian judgements exercised by each individual pursuing self-interest" (Rifkin 1981, p.27).

From its roots in the Cartesian paradigm, the utilitarian social mechanics of Locke and Smith thus succeeded in reducing human beings to selfish egoists devoted mainly to economic production and consumption in the pursuit of endless material abundance.

2. MODERN MYTH: THE MECHANICAL ECONOMY

Modern economics owes much to the scientific world-view. The founders of the neoclassical school, impressed with the spectacular successes of Newtonian physics, strove to create economics as a sister science, "the mechanics of utility and self-interest" (Jevons 1879, cited in Georgescu-Roegen 1975). The major consequence of the mechanical analogue is an entrenched view of economic process as "a self-sustaining circular flow between production and consumption within a completely closed system." By this perception, supply and demand functions continually readjust to each other, "everything...turns out to be just a pendulum movement. One business 'cycle' follows another... If events alter the supply and demand propensities, the economic world returns to its previous position as soon as these events fade out." In short, "**complete reversibility** is the general rule, just as in mechanics" (Georgescu-Roegen 1975, p.348, emphasis added).

2.1 The Worship of Growth

A mechanical economy chugging away in an infinite universe raises the theoretical possibility of unlimited growth. Today economic planners seem to believe "not only in the possibility of continuous material growth, but in its axiomatic necessity" (Georgescu-Roegen 1977). Our "...largely uncritical worship of... economic growth is as central to [capitalism's] nature as the similar veneration of ...divine kingship or doctrinal orthodoxy has been for other regimes" (Heilbroner 1989, p.102).[3] Accordingly, the annual increase in gross national product (GNP) is still taken as every nation's primary indicator of national health. Rates under 3% are considered sluggish but even 3% implies a doubling of economic activity in just 23 years!

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[3] See Simon and Kahn (1984) for an expression of this perspective.

We should note in the context of sustainable development that capitalist states depend on the increasing size of the national economic pie to ensure that the poor receive enough of the national income to survive. Indeed, economic growth is a major instrument of social policy. By sustaining hope for improvement, it relieves the pressure for policies aimed at more equitable distribution of wealth.

Significantly too, while GNP is accepted as a measure of economic welfare, we have no comparable metric for the state of environment or perceived quality of life. This is a revealing comment on societal perceptions, priorities, and the staying power of the materialist paradigm.

3. ECOLOGICAL REALITY

The emerging ecological crisis reveals fatal flaws in the prevailing world-view. There is a fundamental dissonance in economy-environment relationships that must be acknowledged if we are ever to get serious about sustainable development.

3.1 From Environment to Ecosphere

The first step is to recognize that the objectification of the natural world is an artifact of the Cartesian subject-object dualism. In effect, environment-as-separate-entity is a human invention. *We made it up!*

The psychological consequences of this invention are quite profound. By definition, "environment" is its own pejorative, alluding to whatever surrounds some other thing of greater interest or value. Environment "diffidently declares itself to be peripheral, unimportant, not to be taken seriously" (Rowe 1989). We may recognize the environment as a source of resources and sink for wastes, but beyond that the natural world is perceived as a mere static backdrop to human affairs. By this perception there is no compelling need to love, cherish, or even husband nature, to do anything beyond exploiting its bounty to our own advantage. By corollary, impacts of economic activity on environmental processes are perceived to be of little long-term consequence. Should something go awry, a simple retraction or technological fix will set things right.

That the economy has an independent life is a cultural myth, one of our most cherished illusions. The reality is that economy and the environment have always been fully and inextricably integrated everywhere but in the Cartesian mind. For all its political and institutional sophistication, the human economy is "fundamentally directed toward a problem encountered by all other species - the dependence for life on materials from elsewhere in the biosphere" (Rapport 1984). Functionally speaking there is only a single entity, the ecosphere, and humankind has always been part of it. The implications of this reality become clear in the following section.

3.2 Economy as Black Hole: The Thermodynamics of Growth

The mechanical metaphor has inhibited economic theory from acknowledging the Second Law of Thermodynamics. This omission is at the heart of our ecological crisis. The Second Law states that **in any closed isolated system, available energy and matter are continuously and irrevocably degraded to the unavailable state.** (See Georgescu-Roegen 1975, 1977.) Since the global economy operates within an

essentially closed system, the Second Law (the entropy law) is actually the ultimate regulator of economic activity.

All modern economies are dependent on fixed stocks of non-renewable material and energy resources. The Second Law therefore declares that they necessarily consume and degrade the very resource base which sustains them. Our material economies treat other components of the ecosphere as resources and all the products of economic activity (i.e., both the by-products of manufacturing and the final consumer goods) are eventually returned to the ecosphere as waste. Thus, while we like to think of our economies as dynamic, productive systems, **the Second Law states that in thermodynamic terms, all material economic "production" is really "consumption."**

So much for mechanical reversibility! Instead, any form of economic activity dependent on material resources contributes to a constant increase in global net entropy (disorder), through the continuous dissipation of available energy and matter.[4] It follows that contrary to the assumptions of neoclassical theory:

- **there is no equilibrium in the energy and material relationships between industrial economies and the ecosphere**; and

- **sustainable development based on prevailing patterns of resource use is not even theoretically conceivable**.

The thermodynamic interpretation of economic process therefore suggests a new definition of sustainable development in radical contrast to present practice: **sustainable development is development that minimizes resource use and the increase in global entropy**.

3.3 The Special Case of Ecosystems

Ecosystems, like economic systems, depend on fixed stocks of material resources. However, the stuff of ecosystems is constantly being transformed and recycled throughout the system via food-webs at the local level, and biogeochemical cycles on a global scale. In addition, evolution and succession in natural communities tend toward greater net order and resilience.

The material transformations and developmental trends of ecosystems thus appear at first glance to defy the entropy law. **Ecosystems are inherently self-sustaining and self-organizing, and therefore contribute to a reduction in global net entropy**. The organizational property by which living systems continuously produce themselves is known as autopoiesis (Maturana and Varela 1988, p.43). Autopoiesis is a product of the complex, interdependent, relationships and flows linking the major components of the ecosphere. The structural integrity of these relationships is therefore essential for the production and maintenance of the participating components themselves.

Autopoiesis is related to the homeostatic behaviour of the ecosphere. Over geological time life processes have regulated the physical environment of Earth

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[4] For example, a finished automobile represents only a fraction of the energy and material that has been permanently dissipated in the manufacturing process. Similarly, modern energy-subsidized agriculture consumes up to 10 calories for every calorie of food energy produced.

within limits narrow enough that life has been able to persist.[5] As a self-producing self-regulating system, the ecosphere as a whole exhibits an important property of ecosystem dynamics: through numerous positive and negative feedback mechanisms "...[the system] is in many respects self-generating - its productivity and stability determined largely through its internal interactions" (Perry *et al.* 1989).

Autopoiesis is possible only because ecosystems, unlike economic systems, are driven by an **external** source of free energy, the sun. The steady stream of solar energy sustains essentially all biological activity and makes possible the diversity of life on earth. Through photosynthesis, living systems concentrate simple dispersed chemicals and use them to synthesize the most complex substances known. Thus, in contrast to economic systems, ecosystems steadily contribute to the accumulation of concentrated energy, matter, and order within the ecosphere. In thermodynamic terms, photosynthesis is the most important (if not the only) productive process on the planet.

Photosynthesis is the ultimate source of all renewable resources used by the human economy. Moreover, since the flow of solar radiation is constant, steady, and reliable, **resource production in the ecological sector is potentially sustainable over any time scale relevant to humankind.**

But only potentially. Ecological productivity is limited by the availability of nutrients, photosynthetic efficiency, and ultimately the rate of energy input (the "solar flux") itself. Ecosystems therefore do not grow indefinitely. Unlike the economy, which expands through resource conversion and positive feedback, ecosystems are held in "steady-state" or dynamic equilibrium by limiting factors and negative feedback. (See Rees 1989b for examples).

3.4 The Pathology of Economy-Environment Integration

This difference is significant because human beings and their economies are now a dominant component of all the world's major ecosystems. Since our economies are growing and the ecosystems within which they are embedded are not, the consumption of ecological resources everywhere has begun to exceed sustainable rates of biological production. Nearly 40% of terrestrial net primary productivity (photosynthesis) is already being used or co-opted by humans, one species among millions, and the fraction is steadily increasing (Vitousek *et al.* 1986).

Over-harvesting, including species extinction and the outright destruction of whole ecosystems, may eventually undermine the autopoietic organization of the ecosphere and therefore its ability to produce the type of "environment" necessary to sustain human beings. Moreover, the destabilizing effect of over-exploitation is exacerbated by pollution which impairs the remaining productivity of ecosystems. The death of lakes and forest die-back due to acid precipitation in Europe and eastern North America are familiar examples.

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[5] This is a mild form of the Gaia Hypothesis originally proposed by Lovelock (1979), that "the physical and chemical condition of the surface of the Earth... has been, and is, actively made fit and comfortable by the presence of life itself..." Long viewed with skepticism by scientists, the idea of a homeostatic Gaia has begun to attract more adherents from the mainstream for the strength of the testable hypotheses on global feedback mechanisms it has begun to produce (Sattaur 1987, Kerr 1988).

Unfortunately, modern economics is uninformed by autopoiesis and has all but ignored the major "downstream" consequences of pollution - after all, material dissipation is the *entropy* law at work.[6] Society therefore receives few signals from the marketplace that the very basis of our wealth is being permanently eroded.

For example, economists argue that technology and resource substitution through market mechanisms have eliminated concern for resource scarcity (e.g., Simon and Kahn 1984). The reality is that present markets don't even recognize such factors as nutrient recycling, soil building, atmosphere maintenance, and climate stabilization as resources. Thus, while market economics can always price the material inputs to manufacturing, it is virtually silent on the value of ecosphere processes. Not surprisingly, it is these more critical process resources that are becoming increasingly scarce and *there are no substitutes.*

3.5 Consuming the Capital

> The surplus... whether great or small is usually torn from the producers, either by [government or individuals] who by superior force... have established themselves as lords of the soil (Mill 1965, p13).

Clearly, any human activity dependent on the consumptive use of ecological resources (forestry, fisheries, agriculture, waste disposal, urban sprawl onto agricultural land) cannot be sustained indefinitely if it consumes not only the annual production of the ecosphere (the "interest"), but also cuts into the standing stock (the "capital"). Herein lies the essence of our environmental crisis. Persistent trends in key ecological variables indicate that we have not only been living off the interest but also consuming our ecological capital.[7] This is the inevitable consequence of exponential material growth in a finite environment.

Viewing the decline of the ecosphere in the same light as rising standards of living provides a novel perspective on at least one source of our unprecedented wealth. The intersecting curves reveal that throughout the industrial revolution we have been busily converting ecological capital into economic capital. In short, the global economy is almost literally consuming the ecosphere.

This means that much of our wealth is illusion. We have simply drawn down one account (the ecosphere) to add to another (material wealth). It might even be argued that we have been collectively impoverished in the process. Much

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[6] The field of environmental economics is an exception but has focused almost exclusively on means to internalize pollution damage and avoidance costs. Even recent economic prescriptions see "environmental policy" largely as a matter of pollution control subject to variable "environmental conditions and local tastes" among jurisdictions (Baumol and Oates 1988). See Gosselink *et al.* (1974), and Westman (1977) for a broader perspective.

[7] Among the most familiar trends are encroaching deserts (growing by 6 million ha/year); rising sea-levels (1.2-2.2 m by 2100); deforestation (11 million ha/yr); acid precipitation; resultant forest dieback (31 million ha damaged); toxic contamination of food supplies; soil oxidation and erosion (26 billion tonnes/yr in excess of formation); marine pollution, species extinction (1000s/yr); fisheries collapse; draw-down and pollution of water tables everywhere; ozone depletion;, greenhouse gas buildup; and climatic change.

potentially renewable ecological capital has been permanently converted into machinery, plant, and possessions that will eventually wear out and have to be replaced at the cost of additional resources.[8]

Heilbroner (1986, p.75) notes that the origin of surplus in the era of industrial capitalism "has gradually moved from trade through direct wage labour exploitation toward technological rents, and that modern-day profits consist of combinations of all three." We can now add a fourth profit source to Heilbroner's list - **capitalist society gains much of its surplus from the irreversible conversion of biological resources.** (We should note that the form of state capitalism practiced in socialist countries differs little in its ecological effect from the industrial capitalism of Western market economies.)

To put it another way, we've long been enjoying a free ride for which payment has now come due. Forest products, food, and manufactured goods are undervalued in the marketplace to the extent the prices we pay do not include the costs of resource maintenance. Our paychecks and corporate profits are excessive to the extent that the resource base which produced them has been run down. The family's second car may represent capital that was **not** ploughed back into silviculture, soils management, and waste control. In short, the "good life" for some humans has been subsidized at the expense of other life on the planet, including future generations.

4. HUMAN CARRYING CAPACITY

For most species, carrying capacity is the maximum population that can be supported indefinitely in a given habitat without permanently damaging the ecosystem. For human society, carrying capacity can be defined as the maximum rate of resource consumption and waste discharge that can be sustained indefinitely in a defined planning region without progressively impairing ecological productivity and integrity.[9] The corresponding maximum human population is therefore a function of *per capita* rates of resource consumption and waste production (system capacity divided by *per capita* demand).

4.1 Absolute Limits?

The deteriorating ecosphere suggests that human populations and the present scale of economic activity may already exceed global carrying capacity. Many ecological processes have been over-loaded and the long-term dependability of certain critical functions is in jeopardy. Indeed, we may not be far from absolute limits.

Bryson (1989) approaches this issue through a thermodynamic analysis of food production. He shows that we would need about 900 square metres of cropland to produce the average *per capita* food energy requirements assuming year round cropping. With an average growing season of only 180 days, each hectare of agricultural land will theoretically support about 5.5 people (10,000/900)*(180/365).

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[8] The need to reflect the depreciation of ecological capital in national income accounts is increasingly being recognized. (See Pearce *et al.* 1989, UNEP/World Bank 1988).

[9] For opposing views of the utility of this concept, see World Bank (1985).

The present world population density is about 3 persons per arable hectare. Hence we are within less than one population doubling of the "sunshine limit" to growth and at present rates will reach that limit in 35 years (Bryson 1989).[10]

These calculations make no allowances for either resource degradation or technological advances. While such uncertainties make prediction about food limits hazardous, we can state that *per capita* grain production has declined each year since 1984, "falling 14% in over the last four years (Brown 1988, p.6); that available data on erosion and falling water tables suggest "sustainable world food output is now running well below consumption" (Brown 1988, p.7); and that "the backlog of unused agricultural technologies that farmers can draw on in some countries is dwindling" (Brown 1988, p.7). These data give reason enough to ponder absolute limits in a world where the human population is increasing by 88,000,000 per year.

There is another factor to consider, this time related to global stability. The closer we push the ecosphere to its limits, the more likely we are to reach critical thresholds of unpredictable systems behaviour. "At certain points in the unfolding process, individual actions have great significance. This is especially pertinent to the macro-level of human societies and our interactions with natural ecosystems" (Prigogine and Stenges 1984, p.300). The probability of homeostatic breakdown increases the more human beings over-exploit and simplify the ecosphere.

Humankind cannot risk the destabilization of major biophysical systems from which there would be no recovery in the short term (e.g., large shifts in historic patterns of climate). The simple fact is we still live in a state of obligate dependency on the integrity of the ecosphere. From the perspective of carrying capacity, persistent negative ecological trends are clear signals that the present human population and level of economic activity already threaten to disrupt the very processes and relationships which sustain us.

It should be understood that while human society depends on many ecological resources and functions for survival, **carrying capacity is ultimately determined by the single vital resource or function in least supply**. (On the global scale, loss of the ozone layer alone could conceivably do us in.)

Such considerations call seriously to question the Brundtland Commission's route to sustainable development through a five to ten-fold increase in industrial activity. Indeed, it forces a reconsideration of the entire growth ethic, the central pillar of industrial capitalism.

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[10] Recall that if a pond has a lily pad that doubles daily and completely covers the pond in 100 days, the pond is only half covered on the 99th day. The question is, is this the dawn of the 100th day for humankind on earth?

5. CARRYING CAPACITY AND CUMULATIVE ASSESSMENT: DETERMINING THE LIMITS[11]

The widely used techniques of environmental assessment (EA) could be adapted for use in estimating carrying capacity in the context of planning for sustainable development.

5.1 Historic Approaches to Environmental Assessment

Most references to EA refer to the process and activities designed to identify, predict, and evaluate (preferably quantitatively) the likely environmental consequences of a specific development or policy proposal. However, only capital projects involving physical disturbance of the environment are generally assessed. This means that EA does not address numerous other important public and private initiatives affecting environmental quality. The aggregate impacts of routine policy decisions, regulated activities, and management procedures may be collectively greater than those of capital works, but are simply not covered by the process. Also, existing impact assessment requirements in many jurisdictions do not generally apply to purely private sector proposals (which implicitly affirms the primacy of private economic interests over public environmental values). These major gaps in EA practice are not acceptable. Sustainable development requires that the scope and institutional mechanisms for EA-like endeavors be extended to capture the full range of human activities significantly affecting the environment.

Other structural weaknesses of traditional EA must also be addressed if the process is to be useful for sustainable development. First, most EA is still conducted on a project-by-project, short-term basis. In effect, standard practice assumes perfect knowledge of "the environment" and the ability to make accurate predictions of ecological and socioeconomic impacts. These assumptions obviate the need for impact monitoring, while the single project focus of typical assessments ignores the cumulative effects of incremental development.

Nearly 20 years of EA practice have shown this approach to be inadequate if not naive. First, important behaviors of complex dynamic systems under stress have proved not to be readily predictable, and may well be inherently intractable to practical analysis (Holling 1978, Willard 1980, Suter 1981, Barnthouse et al. 1984). Meanwhile, cumulative effects are proving to be "environmental destruction by insignificant increments" in the absence of any broader evaluative context. Global warming, ozone depletion, soil deterioration, falling water tables, species extinction - all such worrisome trends are the cumulative effects of routine economic activity at the level of the ecosphere.

Finally, and perhaps most important, EA is typically still a reactive, quasi-regulatory instrument, expected to have only a marginal effect on project design and implementation. The economy and the proposal are considered to be the independent or driving variables, and the environment and EA the dependent ones. By contrast, sustainable development requires a proactive planning approach in which ecological integrity is the governing factor and the permissible level of economic activity is the dependent variable.

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[11] This section based on Rees 1988a.

Present EA practice reflects the narrow reductionist perspective of the world-view that spawned it, and is ill-suited to the more holistic requirements of sustainable development. If EA is to contribute significantly to reversing negative environmental trends, the conceptual framework and context for implementation needs further development.

5.2 Cumulative Effects and the Regional Connection

This section outlines how improved EA could become an essential component of a regional approach to global sustainable development. The proposed model is radical by today's standards because of its explicit acceptance of absolute ecological constraints on economic activity. Its implementation would therefore require a shift in societal perceptions and attitudes, the adoption of a modified world-view. Ultimately, people must recognize that it has become socially unconscionable to advance an ecologically bankrupt development proposal.

A major force behind the call for sustainable development is concern about the cumulative environmental and social effects of human activity at all spatial scales. Cumulative impacts result from the additive or synergistic effects of numerous actions usually ignored as individually too small to be considered in environmental assessment. Sometimes concern is over cumulative changes in single variables from a variety of similar sources, sometimes over the impacts on numerous variables from various unrelated activities. Most of the known global ecological problems facing us today are the cumulative result of the industrial economy.

Society rarely notices gradual changes in environmental parameters until it is too late for effective mitigative action. As often, however, the homeostasis (negative feedback) of ecosystems "absorbs" incremental impacts for long periods without obvious ill effect. This produces a false sense of security that all is well when, in fact, we are being led into an ecological trap. In either case, the resultant inaction means that a straw is added that breaks the proverbial camel's back. A species, a valuable fishery, or a whole ecosystem may be lost, possibly forever.

Planning for sustainable development will obviously require systematic identification and monitoring of cumulative negative trends in significant environmental variables. Whether these trends are driven wholly by local activity or are the result of more global factors, the necessary corrective action must be implemented at the local level. This suggests that cumulative effects assessment and management might best be carried out within a regional framework. For this purpose, it will probably be necessary to divide existing political units into functional planning regions based on such ecological criteria as climatic and vegetation patterns, soil classification, and watershed boundaries.

5.3 Regional Carrying Capacity and a Role for Environmental Assessment

Measuring cumulative effects has no practical utility unless it is in relation to recognized limits of ecological or social impact within the planning or management region. Working within regional carrying capacity does not preclude some environmental damage in the course of development (buildings and roads must occupy some space); nor does it preclude using nature's services (e.g., organic waste processing and recycling) to capacity. The key is to ensure that sufficient stable ecological capital remains in place to support the anticipated dependent population indefinitely at an acceptable standard of living.

It is already obvious that to achieve sustainable levels of economic activity, society would have to adopt more rigorous and environmentally deterministic approaches to regional planning than at present. Long-term ecological factors rather than short-term market forces would be the primary determinants of land use and resource management decisions as limits are approached.

Persistent deterioration in key ecological variables could not be tolerated. Land use and development patterns would be controlled under sustainable use planning criteria. Each planning region would therefore have to undertake a comprehensive inventory of lands, water, and associated ecological resources, and implement an ambient environmental quality monitoring program. In effect, comprehensive regional monitoring would become an operational form of cumulative environmental assessment (CEA). Within the sustainable development framework, CEA would provide the means to estimate how close we are to developmental limits specified and imposed by the carrying capacity considerations of the regional plan.

This approach also provides the missing context for project-specific EA. Critics of "traditional" EA have long observed that in the absence of a broader policy and planning context, without knowing potentially competing resource uses and values, it is impossible to assess the "significance" of impacts associated with isolated projects. By contrast, the carrying capacity framework enables individual project impacts to be evaluated, as they should be, in light of preceding development, opportunity costs, and the remaining capacity of biophysical and social systems to cope with stress. Meanwhile, project-specific assessments would provide data for the on-going cumulative environmental assessment program, and an opportunity to test specific hypotheses on environment-development relationships.

5.4 The Problem of Inter-Regional Trade

While the notion of carrying capacity is conceptually simple, various factors make it difficult to put into practice. For example, inter-regional flows of, and commercial trade in ecological goods and services, presently obscure the immediate people-land relationship.[12] Because they can import nature's products from outside their own territories, the populations of many regions today unknowingly exceed their local carrying capacity with apparent impunity. In the absence of feedback from the land on their life-styles or economy, there is no direct incentive for such populations to practice sustainable management of local resources. The psychological effect is that people forget their "obligate dependency" on the natural environment. Why should the citizens of Region "A" be concerned about the urbanization of their limited agricultural land when they can always import food from Region "B"?

The problem is, that as one region's population undermines its own environment, it becomes dependent on apparent excess carrying capacity "imported" from other regions over which it has no direct management control. In these circumstances, the populations of some surplus regions could not then rise to the level of their own regional carrying capacity without potentially compromising people in dependent import regions. We should also recognize that the perceived need for foreign exchange already drives some developing countries to export **non-surplus** carrying

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[12] This includes the movement of air and water in natural cycles throughout the ecosphere, and import/export trade in fisheries, forestry, and agricultural products.

capacity, thereby jeopardizing staples production and harming their own people.[13] Neither situation is sustainable.

These last points become potential foci for policy development when we realize: a) there is generally no permanent commitment by export regions to dependent regions, and; b) management practices in the export regions may be undermining ecosystems there as well. Thus, under a carrying capacity approach to sustainable development, inhabitants of significant trading regions might want to contractually formalize their relationships.

The necessary negotiations would be oriented to creating a morally and politically acceptable basis of exchange, and serve a valuable educational function. Documenting the nature of inter-regional dependencies, would both increase public awareness of ecological realities, and contribute to inter-regional equity. For example, importers would have to pay a price not currently accounted for in the market, for reserving extra-territorial carrying capacity. At present, the residents of developed countries are not even aware of the impacts their imports of luxury crops have on such factors as staples production, land use and ownership patterns, and ecological conditions, in exporting developing counties.

Although inter-regional trade reduces the incentive to husband local ecosystems, making it politically more difficult to implement a carrying capacity approach, trade per se is not at fault. For example, if by adopting an ecological development paradigm, the population of each planning region were to achieve intra-regional stability (i.e., no progressive environmental degradation) **regardless of its trade balance**, the cumulative effect would be a sustainable level of development within global carrying capacity (which is, after all, the whole point of the exercise).

5.5 Ecological Accounts and Balance of Trade

By extension, the cumulative assessment - carrying capacity (CA-CC) approach could be used to monitor the total consumption (demand) and production of a wide range of ecological goods and services for each planning region. With increasingly fine-grained analysis, the latter might range from market commodities such as food and forest products, to more fundamental ecosystems components not recognized *per se* in the marketplace, such as essential nutrients.[14]

Monitoring the relationship between cumulative demand and regional capacity for each key component would:

- identify those vital ecological resources and functions in greatest danger of over-exploitation, and thus provide the empirical basis for policy and management initiatives to restore sustainable development;

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[13] Ecological trade is a zero-sum game that can relieve imbalance but not overall scarcity.

[14] North Americans export "grain", but are not accustomed to thinking of it as phosphates, nitrates, etc. removed from the soil. Indeed, agriculture can become a form of mining, and just as non-renewable.

• make it possible to build up a crude set of ecological accounts and hence an estimate of the ecological "balance of trade" for any region, however defined, with the rest of the ecosphere.

Such regional ecological accounts would graphically illustrate inter-regional dependencies and would be followed with as much interest by an informed public as economic current accounts are today. Given the need to garner and maintain public support for the more onerous implications of sustainable development, this feature is a attractive advantage of the CA-CC approach.

5.6 A Context for Sustainable Development

Cumulative assessment and carrying capacity provide powerful conceptual tools for implementing sustainable development on a coordinated regional basis. They also imply an unprecedented level of sociopolitical control over the level and quality of economic and development activity. However, before rejecting this framework as an extreme form of ecological determinism, remember that present approaches systematically **destroy** our potentially renewable ecological capital, and may therefore prove more costly and restrictive in the end.

We should also note that carrying capacity and sustainability merely provide the **context** for development. Numerous other considerations provide the management **content.** Such technical factors as the efficiency of energy use, the sophistication of production and waste control methods, and the level of technology generally; as well as such economic and social considerations as gross regional product, material standard of living, and material expectations, are all determinants of regional carrying capacity.[15] Since all such factors are socially and politically malleable, more policy and planning flexibility is available under the CEA-CC approach than is initially apparent.

While it may make some people uncomfortable, all such variables will necessarily become stronger foci for public policy as environmental limits are breached, **whatever** the development model. Ironically the revitalized laissez-faire attitudes presently sweeping the world must inevitably lead to an increasingly interventionist society.

6. SUSTAINABILITY IN THE REAL WORLD: LIVING ON THE INTEREST

Our analysis of the present pathological relationship between environment and economy and the implications of carrying capacity for future development represent a serious challenge to the central assumptions of our economy and to our present way of life. In essence, compatible economy-environment integration requires that we recognize the reality of ecological limits to material growth and the need to live on the interest of our remaining ecological capital. Assuming that our will to survive can overcome our natural resistance to change, society must soon come to accept the following principles as guidelines on the road to sustainable development.

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[15] For example, improved technology will sustain more people at a given standard of living, or the same number at a higher standard, than before.

• The economy is an integral component of the ecosphere. The future of society is therefore wholly dependent on our ability to restore and maintain the self-producing structure and functional relationships of the ecosphere (autopoiesis). This is in direct opposition to the claim of the Canada's National Task Force on Environment and Economy that "sustainable development does not require the preservation of the current stock of natural resources or any particular mix of...assets" (CCREM 1987, p.3).

• The maximum sustainable level of global economic activity is limited and depends on the condition of the ecosphere. Exceeding current limits will reduce future potential in proportion to the damage done to biospheric productivity.

• We must move from a society oriented to satisfying the artificial wants of a few to one committed to satisfying the basic needs of all. Our present economic system encourages growth in consumption. By contrast, sustainable development requires that we minimize resource throughput and the increase in global net entropy.

• Harvest rates in the renewable resource sectors must be limited to average rates of production and not be responsive to ever-increasing market demand. Bottom line economics encourages the liquidation of ecological capital stock (fish, forests, soil, etc.) By contrast, sustainable development requires that society live on the "interest" of our ecological endowment. **This is not an option but an absolute necessity if we are to have a sustainable future.**

• Rates of waste discharge (including pesticide use) must be limited to the rate at which ecosystems can absorb and degrade the wastes. Significant processing capacity generally exists only for ecologically benign organic waste and nutrients. (Assay for bio-accumulation of toxic substances in food chains can indicate when absorptive capacity for these substances has been exceeded.)

• In the case of carcinogens and similar dangerous compounds zero tolerance is warranted.

• Society at large will have to pay the true costs of goods "production." In general, market prices should reflect producers' costs for ecosystems maintenance (e.g., soils management). In other cases, an entropy tax should be imposed to provide public funds for common property systems maintenance. (An entropy tax on fossil fuels could be used to plant carbon sink forests to help stabilize atmospheric CO_2 levels [Rees 1989c]). Where serious damage has already been done, society may have to devote substantial resources to ecosystems rehabilitation. All this implies significant increases in operating costs and market prices.

• As society makes the above adjustments special measures must be put in place to ensure that the burden does not fall unfairly on working people and the poor. The basic necessities for a decent life must be affordable to all.

• We must recognize that **historic levels of profits may not be compatible with sustainable development**. For example, resources corporations should be required to demonstrate adequate maintenance of the resource base before declaring a dividend.

• Global population control must become an international priority. The maximum sustainable human population (global carrying capacity) is a function of the nature of economic activity, technological sophistication, and mean *per capita* consumption

(material standard of living). All these factors are subject to public policy adjustment. Any population growth beyond the current carrying capacity can only be justified by improved technology or be accompanied by a proportional decline in standard of living.

• New systems of national economic-ecological accounts must be adopted to monitor the ecosphere. Remarkably, macro-economic indicators such as GNP only monitor income flows, not the state of productive capital. Thus, "glowing economic reports...are possible when the policies that generate them are destroying the resource base" (Brown *et al.*,1984, p.195).

• The new indicators might include Adjusted National Product (ANP), "consisting of GNP with the social and environmental costs deducted from it, rather than added to it" (Ekins 1986, p.129). Other accounts should monitor the state of biologically productive assets and key autopoietic processes such as pollution absorption, nutrient cycling, soils maintenance, radiation balance, atmospheric regulation, and primary production (photosynthesis). (The UNEP/World Bank [1988] would call these "satellite accounts," revealing a continuing economic bias).

• In the absence of such accounts, inter-regional trade obscures people's perception of their obligate dependency on the ecosphere. Importing ecological goods and services means importing carrying capacity from elsewhere and encourages people to destroy their own local ecosystems through "development" at no apparent cost to themselves. Many regions and nations with excellent economic accounts (e.g., Japan) would probably be unviable as isolated ecological units.

• Sustainable development requires monitoring cumulative impacts and defining development regions for ecological accounting purposes. In current practice "taking environmental factors into account" usually means that long-term ecological productivity is "traded-off" for short-term economic gain. Thus, while individual developments are approved on economic grounds the cumulative ecological impacts will eventually exceed regional (and global) carrying capacity.

• Seemingly under-developed ecological assets in one region may actually be performing vital functions that are already being fully utilized by people elsewhere. This is most evident when there are markets for specific products but is less obvious in the case of unaccounted vital services. For example, tropical rain forests are of concern to people everywhere as carbon sinks and for their possible role in maintaining atmospheric and climatic equilibria.

• Long-term global sustainability may require that we formalize these hidden relationships. For example, the wealthy industrialized nations of the North might consider purchasing the development rights to the Amazon and other tropical forest regions to preserve their ecological integrity.

• Trade also has important implications for equity in achieving global sustainable development. For example, wealthy nations may import non-surplus carrying capacity from poor regions at great unaccounted costs to the latter. This is the case when the global financial system compels developing nations to grow cash crops for export on their best lands at the expense of local staples production. This leads in turn to over-exploitation of marginal agricultural and forest lands as impoverished local people struggle to survive. Revised inter-regional economic-ecological accounting would help to internalize these real cost factors into the terms of trade.

• When the carrying capacity of a given management region has been reached, ecological factors must necessarily over-ride economic considerations. The next project cannot be built. (If each nation or management region achieves regional ecological stability, the net effect would be global stability. Conversely, if most regions exceed their carrying capacities, global destruction is assured.)

• Well-documented ecological trends such as atmospheric change, forest dieback, and falling *per capita* food production indicate that we have already breached global carrying capacity. (Consider the world as a single development region.) Thus, even current levels of economic activity are not sustainable with present technology. People in the industrialized countries may well have to lower their material expectations and even accept a decline in material standards to achieve global sustainability .

• Economic growth should no longer be considered a basic element of social policy. Social justice and equity considerations may therefore require creative new policies for income redistribution. We may even have to move beyond paid employment as the means of access to the basic requirements of life to some other system of entitlement.

• Sustainable development may force significant restructuring of national economies in the developed nations (for example in the petroleum, automotive, and forestry sectors). This in turn may require new forms of social safety nets to catch and retrain workers displaced from ecologically unsustainable employment.

• Sustainable development reintroduces equity and moral considerations into global economic development. The wealthiest 26% of the world's population consume 80-86% of non-renewable resources and 34-50% of food supplies (WCED 1987). In a limited world, reducing the gap in living standards between the rich and the poor requires that **any capacity for future material economic growth be redirected to the third world**. Forgiving international debt, aid to rehabilitate tropical ecosystems, and programs to develop ecologically appropriate technology for the developing countries are examples of strategies the developed nations might implement to help redistribute global wealth.

• Sustainable development represents an opportunity to shift the emphasis in development from quantitative to qualitative considerations. We might rediscover that development has more to do with community relationship, self-reliance, and personal growth than it does with increased economic capacity.

• Socially sensitive interpretations of sustainable development emphasize the opportunity for a return to community values, local control over resources, community-based development, and other forms of decentralized governance. This too confronts the current trends toward concentrated economic power and centralized political decision-making.

• Global sustainable development demands the development of new forms of international cooperation and regulation to ensure acceptable standards for ecological stability. (No nation can achieve global sustainability in isolation.) This is contrary to the current emphasis on competition, exploitation of comparative advantage, and deregulation as means to stimulate world economic growth.

• Sustainable development presents an opportunity to eliminate the arms race and free up the resources required for planetary rehabilitation. Armaments presently consume a trillion dollars or "more than the total income of the poorest half of

humanity" (WCED 1987, p.297). Brown *et al.*(1988, p.183) have estimated that additional expenditures of less than US $150 billion per year in the 1990s - 15% of current arms expenditures - would be adequate to begin the move toward global sustainable development.

• Optimistically, increasing numbers of nations will come to realize that national security lies more in rehabilitating ecological capital than in retaining military might (See Meyers 1989). In short, the threat to our common ecosphere may bring the people of the global village together to confront our common enemy who is us (with apologies to the late Walt Whitman and Pogo).

Pessimistically...

7. CONCLUSION: DIFFICULT PATH TO A BETTER WORLD

Most discussion of sustainable development in the sociopolitical mainstream today emphasizes the need to sustain economic growth. The assumption is that we can "account for" the environment through greater efficiency of resource use, improved technology, better pollution control, and wider use of environmental assessment. This marginal approach would result in little more than a somewhat better dressed version of the growth-bound *status quo* requiring a minimum of adjustment by either industry or individuals.

This paper paints a dramatically different picture illuminated by the entropy law and the concept of ecological carrying capacity. In this contrasting light the evidence suggests we may be fast approaching absolute limits to material economic growth. We no longer have the luxury of "trading-off" ecological damage for economic benefits if we hope to have a sustainable future. The maintenance of global ecological integrity necessarily becomes our highest priority and must be factored into every local and regional development decision. This is the real meaning of environment-economy integration.

While the conceptual framework merely stresses the obvious - a dependent part cannot grow indefinitely within a limited whole - acceptance that it applies to our ecological dilemma requires a profound shift in societal values and attitudes, and a major restructuring of national and global economies. On the positive side, **the attitudinal changes and policy responses suggested herein have the potential to produce a more politically secure, ecologically stable, and economically just global society.**

Those who argue that my interpretation is extreme and the suggested guidelines forsustainable development utopian (or draconian, depending on your point of view!) have an obligation to refute the analysis. If my basic argument is sound, the real utopians - dreamers of the impossible - are those who still support the material growth ethic and maintenance of our economic status quo.

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